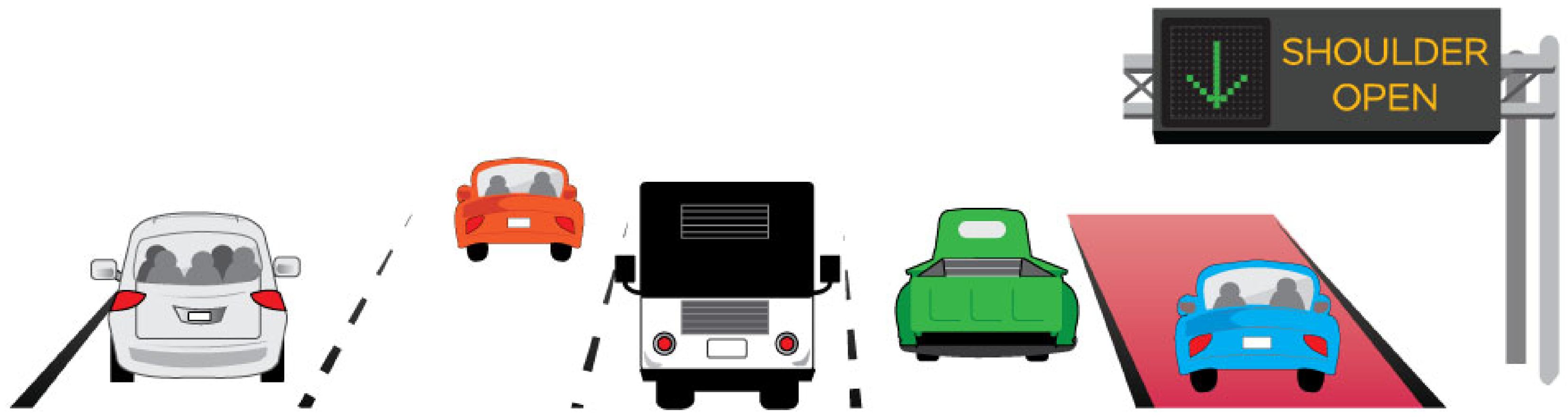
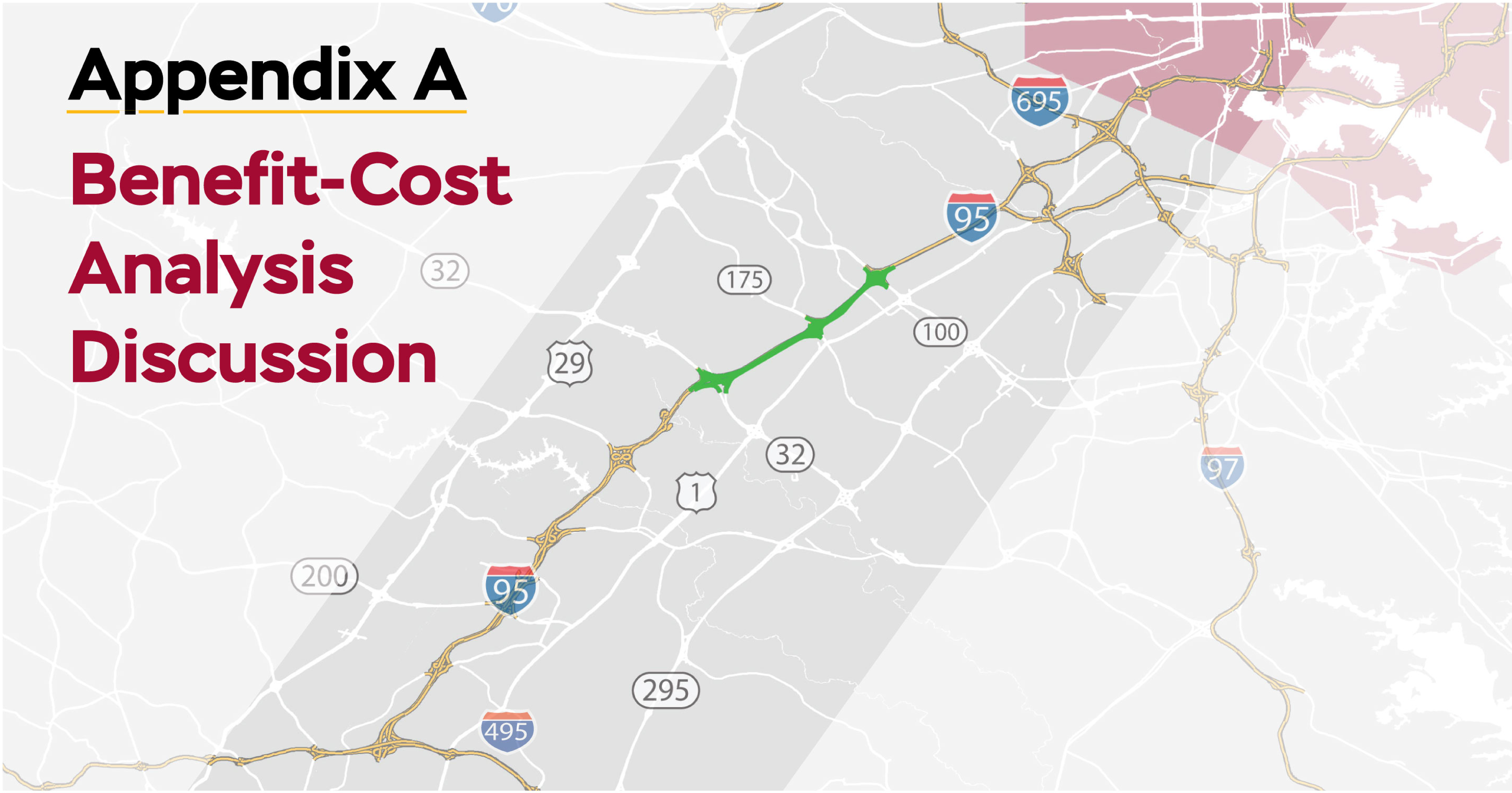


Appendix A

Benefit-Cost Analysis Discussion



MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

I-95 Innovative Active Traffic Management
Benefit-Cost Analysis Supplementary Documentation

FY2017 TIGER Discretionary Grant Program

PREPARED FOR: MARYLAND DEPARTMENT OF TRANSPORTATION, STATE HIGHWAY ADMINISTRATION

OCTOBER 16, 2017

EXECUTIVE SUMMARY

A benefit-cost analysis (BCA) was conducted for the I-95 Innovative Active Traffic Management Project for submission to the U.S. Department of Transportation (USDOT) as a requirement of a discretionary grant application for the TIGER 2017 program. The analysis was conducted in accordance with the benefit-cost methodology as outlined by USDOT in the 2017 TIGER Benefit-Cost Analysis Guidance. The period of analysis corresponds to 22 years and includes two years of construction and 20 years of benefits after operations begin in 2022.

This TIGER project allows the Maryland Department of Transportation's (MDOT) State Highway Administration (MDOT SHA) to innovatively provide congestion relief and safety improvements on I-95 between MD 32 and MD 100. Improvements include part-time shoulder use (PTSU) during peak periods to create outside auxiliary lanes in both directions, interchange ramp improvements, and dynamic signing. Under current conditions, capacity limitations and highway design are resulting in major congestion and safety concerns. The project will innovatively address these issues through a coordinated package of infrastructure improvements that will facilitate safer vehicle movements through this high-traffic corridor.

COSTS

The capital cost for this Project is expected to be $23 million in undiscounted 2016 dollars through 2021. At a 7 percent, real discount rate, these costs are $17.2 million. Operations and maintenance costs are projected to average $48,000 per year in the long term. Over the entire 20-year analysis period these costs accumulate to $960K in undiscounted 2016 dollars, or $363K when discounted at 7 percent.

The Project costs are summarized Table ES-1.

TABLE ES-1: Total Project Costs, in Undiscounted Millions of 2016 Dollars, through 2041

Design Costs	Construction Costs	Operating and Maintenance Costs	Total Project Cost
$2,000,000	$21,000,000	$960,000	$23,960,000

Source: MDOT SHA; WSP Analysis

BENEFITS

In 2016 dollars, the Project is expected to generate $132.9M in discounted benefits using a 7 percent discount rate, relative to a no-build scenario. This is achieved primarily through reduction in Vehicle Hours Traveled (VHT) and safety improvements. The project improvements result in increase in Vehicle Miles Traveled (VMT), which would offset a small part of the travel time and safety improvements through increased fuel consumption, emissions, and additional pavement damage. However, these "disbenefits" are greatly overshadowed by the travel time and safety improvements, such that the overall project Net Present Value is $115M with a Benefit Cost Ratio (BCR) of 7.57. The overall project benefit matrix can be seen in Table ES-2.

Table ES-2: Project Impacts and Benefits Summary, Monetary Values in Millions of 2016 Dollars

Current Status/Baseline & Problem to be Addressed	Change to Baseline/ Alternatives	Type of Impact	Population Affected by Impact	Economic Benefit/Disbenefit)	Summary of Results (at 7% discount rate)	Summary of Results (at 3% discount rate)	Page Reference in BCA
Peak travel time congestion	Add capacity with peak period hard running shoulder/part time shoulder use	Reducing travel time	Residents of MD and nearby States	Reduced travel time	$119.8	$242.2	6-7
Peak travel time congestion	Add capacity with peak period hard running shoulder/part time shoulder use	Improved travel time and better vehicle mileage	Residents of MD and nearby States	Reduced fuel consumption	$6.4	$12.8	7-8
Idling due to congestion	Reduce congestion and idling by increasing capacity and creating more efficient interchanges	Reduced fuel consumption	Residents of MD and nearby States	Reduced emissions	$.22	$.34	10-11
Unsafe interchange geometries	Increase safety with improved roadway geometry and longer merge areas	Fewer crashes	Residents of MD and nearby States	Reduced crashes	$9.3	$15.8	9

Current Status/Baseline & Problem to be Addressed	Change to Baseline/ Alternatives	Type of Impact	Population Affected by Impact	Economic Benefit/Disbenefit)	Summary of Results (at 7% discount rate)	Summary of Results (at 3% discount rate)	Page Reference in BCA
N/A	N/A	Higher VMT	Residents of MD and nearby States	Increased vehicle O&M	(\$1.98)	(\$3.93)	8
N/A	N/A	Higher VMT	Residents of MD and nearby States	Increased pavement damage	(\$.82)	(\$1.63)	9-10

Source: WSP, 2017

The overall Project impacts can be seen in Table ES-3, which shows the magnitude of change and direction of the various impact categories.

Table ES-3: Project Impacts, Cumulative 2022-2041

Category	Unit	Quantity	Direction
Vehicle-Miles Traveled	VMT	10,996,724	▲
Passenger-Hours Traveled	PHT	22,302,792	▼
Fuel Consumed	gallons	805,640	▼
Fatalities	#	1.4	▼
Injury Crashes	#	86.8	▼
Property Damage Only (PDO)	#	287	▼
CO_2 Emissions	tons	49,123	▼
NO_X Emissions	tons	28.2	▼
PM^{10}	tons	0.6	▼
SO_X	tons	0.3	▼
VOC	tons	37.7	▼

Source: WSP, 2017

Finally, table ES-4 summarizes the BCA results. Discounted at 7%, the benefit-cost ratio is 7.57. This high benefit-cost ratio is primarily due to the project's potential to bring significant congestion relief with relatively low capital costs due to the use of existing lanes.

TableES-4: Benefit Cost Analysis Results, Millions of 2016 Dollars

BCA Metric	Project Lifecycle		
	Undiscounted	Discounted (7%)	Discounted (3%)
Total Benefits	$465,693,980	$132,896,669	$265,557,741
Total Costs	$23,960,000	$17,549,054	$20,860,249
Net Present Value (NPV)	$441,733,980	$115,347,615	$244,697,492
Benefit Cost Ratio (BCR)	19.44	7.57	12.73

Source: WSP Analysis

CONTENTS

LIST OF TABLES

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1 INTRODUCTION

A benefit-cost analysis (BCA) was conducted for the I-95 Innovative Active Traffic Management Project for submission to the U.S. Department of Transportation (USDOT) as a requirement of a discretionary grant application for the TIGER 2017 program. The following section describes the BCA framework, evaluation metrics, and report contents.

1.1 BCA FRAMEWORK

A BCA is an evaluation framework to assess the economic advantages (benefits) and disadvantages (costs) of an investment alternative. Benefits and costs are broadly defined and are quantified in monetary terms to the extent possible. The overall goal of a BCA is to assess whether the expected benefits of a project justify the costs from a national perspective. A BCA framework attempts to capture the net welfare change created by a project, including cost savings and increases in welfare (benefits), and project capital and operating costs.

The BCA framework involves defining a Base or “No Build” Case, which is compared to the “Build” Case, where the grant request is awarded and the project is built as proposed. The BCA assesses the incremental difference between the Base Case and the Build Case, which represents the net change in welfare. BCAs are forward-looking exercises which seek to assess the incremental change in welfare over a project life-cycle. The importance of future welfare changes is determined through discounting, which is meant to reflect both the opportunity cost of capital as well as the societal preference for the present.

The analysis was conducted in accordance with the benefit-cost methodology as recommended by the USDOT in the 2017 TIGER Benefit-Cost Analysis Guidance.[1] This methodology includes the following analytical assumptions:

- Assessing benefits with respect to each of the five long-term outcomes defined by the USDOT;
- Defining existing and future conditions under a No Build base case as well as under the Build Case
- Estimating benefits and costs during project construction and operation, including 20 years of operations beyond the Project completion when benefits accrue;
- Using USDOT recommended monetized values for reduced fatalities, injuries, property damage, travel time savings, and emissions, while relying on best practices for monetization of other benefits;

[1] U.S. Department of Transportation. Benefit-Cost Analysis Guidance for TIGER Applicants. 2017.

- Presenting dollar values in real 2016 dollars. In instances where cost estimates and benefits valuations are expressed in historical dollar years, using an appropriate Consumer Price Index (CPI) to adjust the values;
- Discounting future benefits and costs with real discount rates of 7 percent and 3 percent (sensitivity analysis) consistent with USDOT guidance;

1.2 PRISM

This benefit cost analysis was done using PRISM™, a benefit cost analysis tool that uses a methodology consistent with the most recent guidelines developed by USDOT. The tool determined benefits according to the following five categories: Quality of Life; Economic Competitiveness; Safety; State of Good Repair; and Environmental Sustainability.

1.3 REPORT CONTENTS

This report is organized as follows. Section 2 contains the project background and general BCA assumptions. It also provides a high-level summary of the project benefits and costs. Section 3 provides details behind benefit and cost calculations. Section 4 summarizes the BCA results and sensitivity analysis. The cumulative benefits and costs, and a full tabular summary of the BCA are included in the appendix.

2 PROJECT OVERVIEW

2.1 DESCRIPTION

The I-95 Innovative Traffic Management Project would allow MDOT SHA to innovatively provide congestion relief and safety improvements on I-95 between MD 32 and MD 100 in Howard County. The proposed improvements are an opportunity to provide a model of efficient, innovative, cost-effective active traffic management using existing right-of-way for other jurisdictions and states across the country. Improvements include part-time shoulder use (PTSU) during peak periods to create outside auxiliary lanes in both directions, interchange ramp improvements, and dynamic signing.

Under current conditions, capacity limitations and highway design are creating major safety and congestion concerns. Crash rates in the project corridor are notably higher than elsewhere in the Maryland state highway network, making this a high-priority safety project. Over the past few years, there have been hundreds of accident-related injuries as well as multiple fatalities. The project will innovatively address these issues through a coordinated package of infrastructure improvements that will facilitate safer and more efficient vehicle movements through this high-traffic corridor.

The project would have a catalytic effect in the growing area of economic opportunities and population growth, connecting residents to jobs, amenities, and opportunities, while at the same time creating a model of innovative congestion management and crash reduction that maximizes efficient use of state and federal funds.

This TIGER IX project addresses safety and congestion issues on I-95 in the high-growth area connecting the Washington, DC and the Baltimore, MD metropolitan areas. Together, these two metropolitan areas compose approximately three million people. Central Maryland, in which this project is located, contains close to half of the state’s population and continues to lead the state’s population growth. Additionally, this corridor is proximate to and provides connection for over 50 federal agencies, universities, Fortune 500 companies, technology, defense, and health care companies. A large percentage of the state’s jobs are in this corridor; furthermore many jobs outside of the corridor located in points east and west of I-95 are still served by I-95, making it critical to people’s ability to travel to and from their place of work.

2.2 GENERAL ASSUMPTIONS

Project design is scheduled to be completed by 2019, while construction begins in 2020 and ends in 2021. The project benefits are assumed to start in 2022, and are analyzed for a 20-year period through 2041. All costs and benefits are calculated for the "Build" case relative to the "No-build" case, and are expressed in constant 2016 dollars. A real discount rate of 7 percent is used to discount costs and benefits to their present values.

2.3 PROJECT COSTS

2.3.1 *CAPITAL COSTS*

This project involves the following improvements:

1. Construct a part-time shoulder use (PTSU) lane from the westbound MD 32 ramp to the westbound MD 100 ramp, and from the MD 100 on-ramp to the MD 175 off-ramp.
2. Extend the acceleration lane from the eastbound MD 175 ramp onto I-95 Southbound.
3. Re-stripe the furthest right mainline through-lane at the MD 175 interchange to create a choice lane.

Table 1 summarizes the project schedule and costs.

Table 1: Project Schedule and Costs, Millions of 2016 Dollars

Variable	Value
Construction Start	2020
Construction End	2021
Construction Duration	2 years
Project Opening	2022
Capital Cost – Construction	$21M
Capital Cost – Design	$2M
O&M Cost	$48K

Source: MDOT SHA, WSP Analysis

2.3.2 OPERATIONS AND MAINTENANCE COSTS

Operating and Maintenance (O&M) costs have been estimated based on an assumed per lane mile cost of $10,000. This is a conservative (high) value, compared with the range of values seen in the research literature, and identified through other planning studies conducted by the BCA study team. For example, the Victoria Transport Policy Institute, in its Benefit Cost Analysis guidance[2] reports a cost per lane mile for routine maintenance of $4,400 in 2004 (based on Texas DOT data).

The operational distance for the PTSU is 4.8 lane-miles. Using $10,000/lane-mile as the metric for O&M, total O&M cost is estimated at $48,000 per year in 2016 dollars.

2.4 PROJECT BENEFITS

The project improvements are projected to lead to reduced travel times or Vehicle Hours Traveled (VHT). The value of reduced VHT is quantified as the value of travel time savings for road users. Even though the traffic demand model forecasts an increase in VMT through 2040, improved traffic flow and reduced idling would lead to reduced fuel consumption and emissions. The project would also lead to improved safety and reduced crashes. However, there are several disbenefits arising from the increased VMT that offset the benefits to a small degree. These are increased vehicle O&M costs and increased pavement damage that entails higher maintenance costs. Details behind how these benefits are quantified are in section 3.

[2] Victoria Transport Policy Institute, Transportation Cost and Benefit Analysis II – Roadway Costs, retrieved from http://www.vtpi.org/tca/tca0506.pdf

Table 2: Project Benefits by Long-Term Outcome Category

Long-Term Outcome	Benefit (Disbenefit) Category	Description	Monetized	Quantified	Qualitative
Economic Competitiveness	Travel time savings	Due to improved traffic flow and reduced VHT/PHT	√		
	Vehicle operating costs	This is a disbenefit due to increased VMT	√		
	Fuel savings	Higher average traffic speeds and lower idling leads to less fuel consumption	√		
Safety	Reduced crashes	Improved safety	√		
State of Good Repair	Increased road damage	This is a disbenefit due to increased VMT	√		
Environmental Sustainability	Reduced emissions	Lower fuel consumption leads to reduced emissions	√		

Source: WSP Analysis

3 BENEFIT-COST ANALYSIS DATA AND ASSUMPTIONS

3.1 DEMAND PROJECTIONS

The traffic demand model projected VMT and VHT for trucks and automobiles through 2040 for both the Build and No-build scenarios. VMT and VHT for prior years were interpolated using a compound average growth rate (CAGR) between 2015 and 2040. The same CAGR was used to generate values for 2041.

The resulting demand projections are presented in the following table.

Table 3: No Build and Build Demand Projections (Annual, 000s)

Variable	Project Opening Year (2022)		Final Year of Analysis (2041)	
	No Build	Build	No Build	Build
Truck VMT	1,376,852	1,376,919	1,865,240	1,867,040
Auto VMT	22,660,337	22,660,311	26,604,623	26,604,008
Truck VHT	49,582	49,577	101,916	101,734
Auto VHT	822,780	822,723	1,387,174	1,385,257

Source: MDOT SHA; WSP Analysis

3.2 ECONOMIC COMPETITIVENESS

This project would contribute to increasing the economic competitiveness of the region through improvements in the mobility of people and goods in the study area. Two types of societal benefits are measured in the assessment of economic competitiveness: travel time savings and vehicle operating savings. Reduced VHT leads to benefits to the road users in terms of the value of travel time. The travel time savings are about 73,000 PHT in 2022, and 22.3M total PHT through 2041. Faster travel times and less idling leads to lower fuel consumption by about 33,000 gallons in 2022 and 8.3M gallons through 2041. However, higher VMT leads to increased vehicle operating costs. Throughout the analysis period between 2022-2041, the project leads to about 11M additional VMT, which leads to a $6.84M increase in vehicle operating costs. These results are summarized in Table 4.

Table 4: Economic Competitiveness Estimation of Benefits, Millions of 2016 Dollars

Benefit	Project Opening Year		Project Lifecycle	
	Undiscounted	Discounted (7%)	Undiscounted	Discounted (7%)
Travel time savings	$1.19M	$.79M	$427.23M	$119.78
Fuel Savings	$.08M	$.05M	$22.31M	$6.41M
Vehicle operating costs	($0.03M)	($0.02M)	($6.84M)	($1.98M)

Source: WSP Analysis

3.2.1 *TRAVEL TIME SAVINGS*

Travel time savings includes in-vehicle travel time savings for auto drivers and passengers as well as truck drivers. Travel time is considered a cost to users, and its value depends on the disutility that travelers attribute to time spent traveling. A reduction in travel time translates into more time available for work, leisure, or other activities. The assumptions used in the estimation of travel time savings are presented in the following table.

Table 5: Travel Time Savings Assumptions and Sources

Variable	Unit	Value	Source
Vehicle Hours Traveled (VHT)	VHT	22.3M	MDOT SHA Traffic forecast for 2040. Interpolation by WSP using CAGR from 2015.
Average vehicle occupancy	Persons per Vehicle	1.2	MDOT SHA/WSP traffic assumption
Value of time (automobile)	$2016	$14.83	USDOT TIGER Guidance
Value of time (truck)	$2016	$28.53	USDOT TIGER Guidance
Value of time real growth rate	% p.a.	1.2%	USDOT TIGER Guidance

Source: MDOT SHA; WSP Analysis

3.2.2 *FUEL SAVINGS*

Reduced idling time and improved traffic flow due to this project are estimated to reduce about 8.3M gallons of fuel through 2041. The benefit of reduced fuel consumption is monetized as follows. First the Federal gasoline (Diesel) tax and Average State gasoline (Diesel) Tax are subtracted from the forecasted prices for gasoline (Diesel). The forecasted prices are per US Energy Information Administration (EIA)'s Annual Energy Outlook 2017[3]. The forecasted prices, net of taxes, are then multiplied by the respective fuel savings for automobiles and trucks for every year in the analysis period, to calculate total annual savings. The assumptions for fuel savings are summarized in the table below.

Table 6: Fuel Cost Savings Assumptions and Sources

Variable	Unit	Value	Source
Federal Gas Tax	$2016	$.184	Federation of Tax Administrators, American Petroleum Institute
Federal Diesel Tax	$2016	$.244	Federation of Tax Administrators, American Petroleum Institute
State Gas Tax	$2016	$.32	Federation of Tax Administrators, American Petroleum Institute
State Diesel Tax	$2016	$.32	Federation of Tax Administrators, American Petroleum Institute
Motor Gasoline Price Forecast (2041)	$2016	$3.31	US EIA 2017
Diesel Price Forecast (2041)	$2016	$4.08	US EIA 2017
Total Gasoline Saved (2022-2041)	Gallons	7.95M	MDOT SHA traffic forecast, WSP Analysis
Total Diesel Saved (2022-2041)	Gallons	335.34K	MDOT SHA traffic forecast, WSP Analysis

Source: WSP Compilation

[3] Table 12: Petroleum and Other Liquids Prices

3.2.3 *OPERATING COST DISBENEFITS*

Vehicle operating costs include the cost of fuel, as well as maintenance and repair, replacement of tires, and the depreciation of the vehicle over time. Operating cost rates per vehicle mile travelled (VMT) are used to calculate the vehicle operating cost disbenefits. Estimates of VMT and unit costs for each component of vehicle operating cost are applied to calculate the total vehicle operating cost. The assumptions used in the estimation of vehicle operating costs are presented in the following table. This table also includes additional out-of-pocket operating costs such as user fees and parking fees. The total vehicle operating cost disbenefits for this project is estimated at about $1.99M discounted at 7%.

Table 7: Operating Cost Savings Assumptions and Sources

Variable	Unit	Value	Source
Auto Maintenance and Repair	2016$/VMT	$.053	AAA[4] "Your Driving Costs" 2016
Auto Tires Cost	2016$/VMT	$.010	AAA "Your Driving Costs" 2016
Auto Depreciation	2016$/VMT	$.251	AAA "Your Driving Costs" 2016
Truck Maintenance and Repair	2016$/VMT	$.158	ATRI[5] 2016 Update
Truck Tires Cost	2016$/VMT	$.044	ATRI 2016 Update
Truck Depreciation	2016$/VMT	$.309	AAA "Your Driving Costs" 2016

Source: WSP Compilation

3.3 SAFETY

The safety benefits assessed in this analysis include a reduction in fatalities and injuries, as well as a reduction in other property damage crash costs resulting directly from the project.

For the project area, historical crash data for 2014 shows 1 fatality, 62 injuries, and 205 property damage instances. Several Crash Modification Factors (CMF) were found in the CMF Clearinghouse for each of the improvements in this project. Since it was not possible to map the crash data to each type of improvement and its CMF, an average CMF of .93 was used. This translates to .07 reduced fatalities, 4.34 reduced injuries, and 14.35 reduced property damage instances per year. Through 2041, this translates to 1.4 reduced fatalities, 86.8 reduced injuries, and 287 property damage instances. To be conservative, no growth rate was assumed in the accident rates for future years. The number of injuries were converted to a MAIS scale and monetized per U.S. DOT guidance.

[4] The American Automobile Association

[5] The American Transportation Research Institute

The safety assumptions and results are summarized below.

Table 8: Safety Estimation of Benefits, Millions of 2016 Dollars

Benefit	Project Opening Year		Project Lifecycle	
	Undiscounted	Discounted (7%)	Undiscounted	Discounted (7%)
Reduced Fatalities	$.67M	$.45M	$13.44M	$5.08M
Reduced Injuries	$.50M	$.33M	$9.97M	$3.76M
Reduced Property Damages	$.06M	$.04M	$1.22M	$.46M

Source: WSP Analysis

Table 9: Safety Benefits Assumptions and Sources

Variable	Unit	Value	Source
Historical number of fatalities	Per year	1	MDOT SHA
Historical number of injuries	Per year	62	MDOT SHA
Historical PDOs	Per year	205	MDOT SHA
Crash Modification Factor	factor	.93	CMF Clearinghouse

Source: MDOT SHA; WSP Compilation

3.4 STATE OF GOOD REPAIR

The state of good repair benefits assessed in this analysis include the disbenefit of increased pavement damage due to increased VMT. This is calculated using the per VMT dollar value of pavement damage and the total VMT increase by mode. Values were escalated from 2000 dollars to 2016 dollars as per the USDOT TIGER guidance. The increased VMT is expected to cost about $824K in 7% discounted disbenefits through 2041.

Table 10: State of Good Repair Estimation of Benefits, Millions of 2016 Dollars

Benefit	Project Opening Year		Project Lifecycle	
	Undiscounted	Discounted (7%)	Undiscounted	Discounted (7%)
Pavement Damage Disbenefit	($0.01M)	($0.01M)	($2.83M)	($.82M)

Source: WSP Analysis

The assumptions used in the estimation of pavement damage disbenefits are presented in the following table.

Table 11: State of Good Repair Benefits Assumptions and Sources

Variable	Unit	Value	Source
Truck VMT Increase	VMT	17.13M	MDOT SHA; WSP Analysis
Auto VMT Decrease	VMT	6.13M	MDOT SHA; WSP Analysis
Truck average pavement cost	$2016/VMT	$.045/VMT	FHWA
Auto average pavement cost	$2016/VMT	$0.0014/VMT	FHWA

Source: WSP Compilation

3.5 ENVIRONMENTAL SUSTAINABILITY

This project will create environmental and sustainability benefits relating to reduction in air pollution associated with decreased fuel consumption. Five forms of emissions were identified, measured and monetized, including: nitrous oxide, particulate matter, sulfur dioxide, volatile organic compounds, and carbon dioxide.

First, the total grams of emissions for each type of emission in 2015 were estimated using emissions rates per VMT (according to the California Air Resources Board's EMFAC database) and total VMT in 2015 for automobiles and trucks. Next, this was divided by the total fuel consumption to estimate emissions/gallon for each type of emission for automobiles and trucks. This emission rates for automobiles and trucks were assumed constant, and multiplied by the total gallons of gasoline and diesel savings respectively for each year.

The volume of reduced emission for each pollutant was then multiplied by the respective value of metric ton, consistent with the 2017 TIGER guidance. Greenstone and Wolverton (2013)[6] find that the benefit of reducing greenhouse gases (GHGs) in the U.S is on average 7-10 percent of the global benefit across scenarios analyzed with the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model[7].

To account for only the domestic cost of carbon, using the research findings above, only 5 percent of the SCC values were considered in this analysis. For present value calculations, the social cost of carbon was discounted at a 3 percent discount rate, consistent with the USDOT's guidance.

Table 12: Environmental Sustainability Estimation of Benefits, 2016 Dollars (note: numbers not scaled)

Benefit	Project Opening Year		Project Lifecycle	
	Undiscounted	Discounted (7%)	Undiscounted	Discounted (7%)
Carbon Emissions	$474	$397	$154,803	$88,124
NOX Emissions	$870	$579	$228,995	$66,514
SOX Emissions	$122	$81	$30,685	$8,963
PM Emissions	$414	$276	$106,575	$31,050
VOC Emissions	$309	$206	$77,637	$22,685

Source: WSP Analysis

The assumptions used in the estimation of environmental sustainability benefits are presented in the following table.

Table 13: Environmental Sustainability Benefits Assumptions and Sources

Variable	Unit	Value	Source
Carbon Emission Rate per Gallon of Diesel	Grams/Gallon	8,128	WSP Analysis
Carbon Emission Rate per Gallon of Gasoline	Grams/Gallon	267	WSP Analysis
NOX Emission Rate per Gallon of Diesel	Grams/Gallon	37.8	WSP Analysis
NOX Emission Rate per Gallon of Gasoline	Grams/Gallon	0.09	WSP Analysis
SOX Emission Rate per Gallon of Diesel	Grams/Gallon	0.09	WSP Analysis
SOX Emission Rate per Gallon of Gasoline	Grams/Gallon	0.00	WSP Analysis

[6] Greenstone, M., Kopits, E, and Wolverton, A. 2013. Developing a social cost of carbon for U.S. regulatory analysis: A methodology and interpretation. Review of Environmental Economics and Policy 7(1):23–46.
[7] Tol, R. 2002b. Estimates of the damage costs of climate change. Part II: Dynamic estimates. Environmental and Resource Economics 21: 135–60.

PM Emission Rate per Gallon of Diesel	Grams/Gallon	.20	WSP Analysis
PM Emission Rate per Gallon of Gasoline	Grams/Gallon	0.00	WSP Analysis
VOC Emission Rate per Gallon of Diesel	Grams/Gallon	2.62	WSP Analysis
VOC Emission Rate per Gallon of Gasoline	Grams/Gallon	.21	WSP Analysis
Carbon Domestic Effect Adjustment Factor (i.e. how much values are reduced by)	Factor	95%	Greenstone, M., Kopits, E, and Wolverton, A. 2013. Developing a social cost of carbon for U.S. regulatory analysis: A methodology and interpretation. Review of Environmental Economics and Policy 7(1):23–46; WSP Analysis

4 SUMMARY OF RESULTS

4.1 EVALUATION MEASURES

The benefit-cost analysis converts potential gains (benefits) and losses (costs) from the Project into monetary units and compares them. The following common benefit-cost evaluation measures are included in this BCA:

- Net Present Value (NPV): NPV compares the net benefits (benefits minus costs) after being discounted to present values using the real discount rate assumption. The NPV provides a perspective on the overall dollar magnitude of cash flows over time in today's dollar terms.
- Benefit Cost Ratio (BCR): The evaluation also estimates the benefit-cost ratio; the present value of incremental benefits is divided by the present value of incremental costs to yield the benefit-cost ratio. The BCR expresses the relation of discounted benefits to discounted costs as a measure of the extent to which a project's benefits either exceed or fall short of the costs.
- Internal Rate of Return (IRR): The IRR is the discount rate which makes the NPV from the Project equal to zero. In other words, it is the discount rate at which the Project breaks even. Generally, the greater the IRR, the more desirable the Project.
- Payback Period: The payback period refers to the period required to recover the funds expended on a Project. When calculating the payback period, the time value of money (discounting) is not considered.

4.2 BCA RESULTS

The table below presents the evaluation results for the project. Results are presented in undiscounted, discounted at 7 percent and discounted at 3 percent (sensitivity) as prescribed by the USDOT. All benefits and costs were estimated in constant 2016 dollars over an evaluation period extending 20 years beyond system completion in 2021.

For the analysis period, the total benefits are $465.7M in undiscounted $2016, $132.9M if discounted at 7%, $265.6M if discounted at 3%. Total costs are $24M in undiscounted $2016, $17.5M if discounted at 7%, $20.9M if discounted at 3%.

Using a 7% discount rate, the project NPV is $115M with a benefit-cost ratio of 7.57. Using a 3% discount rate, the project NPV is $244.7M with a benefit-cost ratio of 12.73.

Table 14: Benefit Cost Analysis Results, Millions of 2016 Dollars

BCA Metric	Project Lifecycle		
	Undiscounted	Discounted (7%)	Discounted (3%)
Total Benefits	$465,693,980	$132,896,669	$265,557,741
Total Costs	$23,960,000	$17,549,054	$20,860,249
Net Present Value (NPV)	$441,733,980	$115,347,615	$244,697,492
Benefit Cost Ratio (BCR)	19.44	7.57	12.73

Source: WSP Analysis

The benefits over the project lifecycle are presented in the table below by USDOT long-term outcome category.

Table 15: Benefits by Long-Term Outcome, Millions of 2016 Dollars

Long-Term Outcome	Project Lifecycle		
	Undiscounted	Discounted (7%)	Discounted (3%)
Quality of Life / Livability	N/A	N/A	N/A
Economic Competitiveness	$443,298,495	$124,202,596	$251,040,382
Safety	$24,628,717	$9,301,510	$15,803,559
State of Good Repair	($2,831,927)	($824,774)	($1,629,720)
Environmental Sustainability	$598,695	$217,337	$343,520

Source: WSP Analysis

A detailed project cost and benefit table, and the cumulative project cost and benefit chart is shown in the appendix. The project's cumulative benefits outweigh the cumulative costs in 2027.

4.3 SENSITIVITY TESTING

A sensitivity analysis is used to help identify which variables have the greatest impact on the BCA results. This analysis can be used to estimate how changes to key variables from their preferred value affect the results and how sensitive the results are to these changes. This allows for the assessment of the strength of the BCA, including whether the results reached using the preferred set of input variables are significantly different by reasonable departures from those values.

Since travel time savings account for most the project benefits, a sensitivity analysis was performed where the PHT benefits were reduced to 75% of their expected values. The results BCR was 5.81 and NPV was $84.49M, using a 7% discount rate. Reducing the PHT reduction to 50% yields a BCR of 4.05 and NPV of $53.55M, using a 7% discount rate.

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Table 16: Project Cost and Benefits

	Costs		*Benefits*								*Net Benefits*	
Year	**CapEx & O&M (Undiscounted)**	**Costs (7% Discounted)**	**Travel Time Savings**	**Fuel Consumption**	**Emissions**	**Safety**	**Vehicle O&M**	**Pavement Damage**	**Total Benefits (Undiscounted)**	**Total Benefits Discounted @ 7%**	**Net Benefits (Undiscounted)**	**Net Benefits (Discounted @ 7%)**
2018	$1,000,000	-$873,439										
2019	$1,000,000	-$816,298										
2020	$10,500,000	$8,010,400							-		-$10,500,000	-$8,010,400
2021	$10,500,000	$7,486,355							-		-$10,500,000	-$7,486,355
2022	$48,000	$31,984	1,192,136	77,120	2,188	1,231,436	(25,735)	(10,976)	2,466,169	1,643,393	$2,418,169	$1,611,409
2023	$48,000	$29,892	2,483,427	158,513	4,486	1,231,436	(52,427)	(22,306)	3,803,128	2,368,588	$3,755,128	$2,338,696
2024	$48,000	$27,936	3,880,106	243,644	6,866	1,231,436	(80,099)	(33,999)	5,247,953	3,054,679	$5,199,953	$3,026,742
2025	$48,000	$26,109	5,388,758	335,673	9,341	1,231,436	(108,778)	(46,065)	6,810,366	3,704,864	$6,762,366	$3,678,755
2026	$48,000	$24,401	7,016,339	431,654	11,915	1,231,436	(138,488)	(58,511)	8,494,344	4,318,746	$8,446,344	$4,294,345
2027	$48,000	$22,804	8,770,192	527,410	14,589	1,231,436	(169,256)	(71,348)	10,303,023	4,895,741	$10,255,023	$4,872,936
2028	$48,000	$21,313	10,658,076	622,070	17,366	1,231,436	(201,110)	(84,584)	12,243,254	5,437,216	$12,195,254	$5,415,903
2029	$48,000	$19,918	12,688,176	728,273	20,163	1,231,436	(234,077)	(98,229)	14,335,743	5,950,100	$14,287,743	$5,930,181
2030	$48,000	$18,615	14,869,138	845,285	23,145	1,231,436	(268,185)	(112,293)	16,588,527	6,434,840	$16,540,527	$6,416,225
2031	$48,000	$17,397	17,210,086	968,104	26,351	1,231,436	(303,462)	(126,785)	19,005,729	6,890,369	$18,957,729	$6,872,971
2032	$48,000	$16,259	19,720,649	1,098,763	29,573	1,231,436	(339,939)	(141,717)	21,598,764	7,318,349	$21,550,764	$7,302,090
2033	$48,000	$15,196	22,410,986	1,213,692	32,915	1,231,436	(377,646)	(157,098)	24,354,285	7,712,340	$24,306,285	$7,697,145
2034	$48,000	$14,201	25,291,820	1,349,729	36,379	1,231,436	(416,613)	(172,938)	27,319,813	8,085,654	$27,271,813	$8,071,453
2035	$48,000	$13,272	28,374,461	1,483,983	39,969	1,231,436	(456,872)	(189,250)	30,483,727	8,432,034	$30,435,727	$8,418,761
2036	$48,000	$12,404	31,670,839	1,650,004	43,689	1,231,436	(498,454)	(206,043)	33,891,471	8,761,562	$33,843,471	$8,749,158
2037	$48,000	$11,593	35,193,540	1,789,292	47,542	1,231,436	(541,393)	(223,330)	37,497,087	9,059,743	$37,449,087	$9,048,150
2038	$48,000	$10,834	38,955,835	1,938,334	51,532	1,231,436	(585,723)	(241,121)	41,350,293	9,337,364	$41,302,293	$9,326,529
2039	$48,000	$10,125	42,971,720	2,113,775	55,888	1,231,436	(631,476)	(259,428)	45,481,914	9,598,755	$45,433,914	$9,588,629
2040	$48,000	$9,463	47,255,954	2,282,116	60,179	1,231,436	(678,690)	(278,264)	49,872,731	9,837,100	$49,824,731	$9,827,637
2041	$48,000	$8,844	51,824,095	2,450,550	64,619	1,231,436	(727,398)	(297,641)	54,545,660	10,055,233	$54,497,660	$10,046,389
Total	$23,960,000	$14,169,581	427,826,333	22,307,983	598,695	24,628,717	(6,835,821)	(2,831,927)	465,693,980	132,896,669	$443,733,980	$117,037,352

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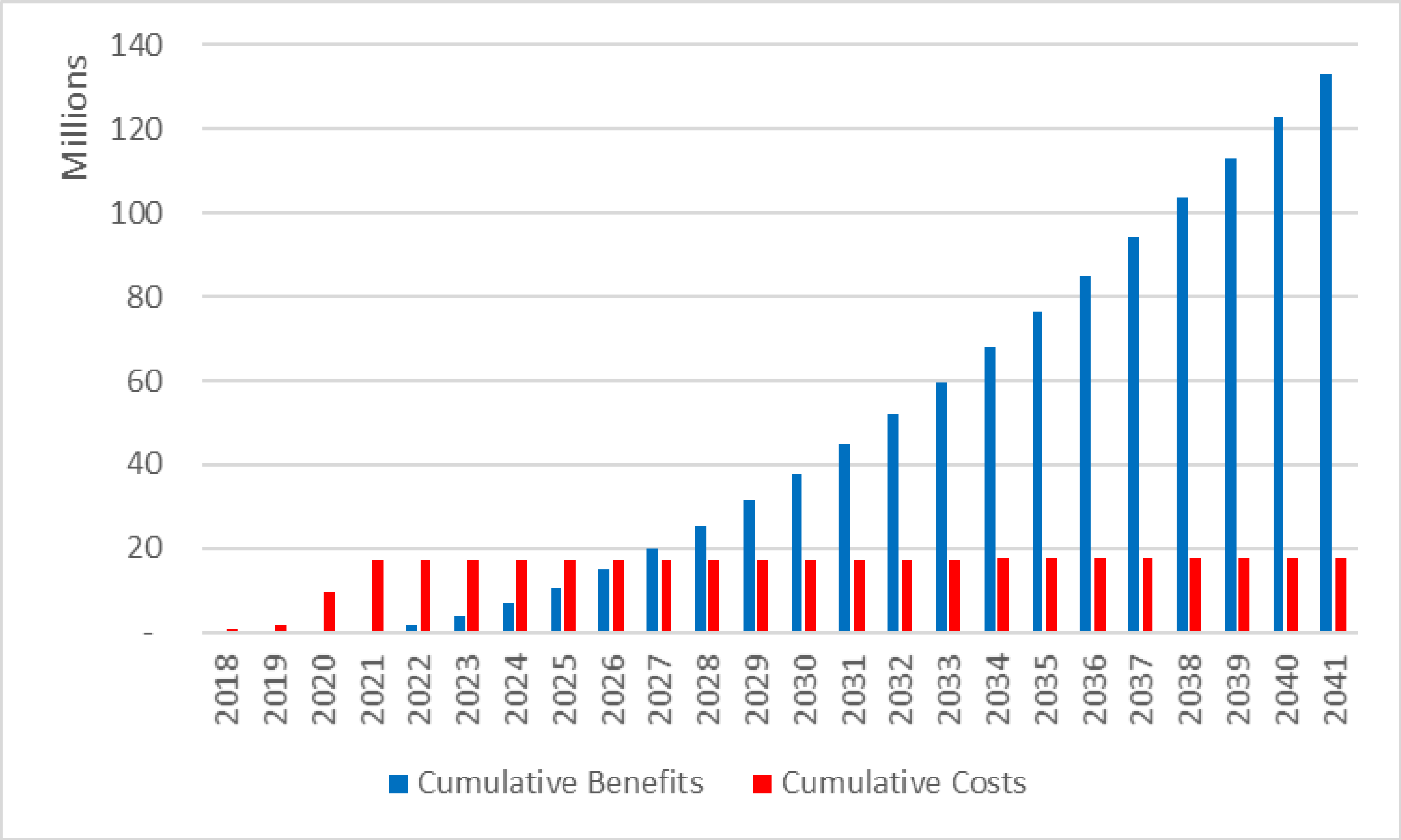
Figure 1: Project Cumulative Costs and Benefits (7%, Breakeven in 2027)



	Costs		*Benefits*								*Net Benefits*	
Year	**CapEx & O&M (Undiscounted)**	**Costs (7% Discounted)**	**Travel Time Savings**	**Fuel Consumption**	**Emissions**	**Safety**	**Vehicle O&M**	**Pavement Damage**	**Total Benefits (Undiscounted)**	**Total Benefits Discounted @ 7%**	**Net Benefits (Undiscounted)**	**Net Benefits (Discounted @ 7%)**
2018	$1,000,000	-$873,439										
2019	$1,000,000	-$816,298										
2020	$10,500,000	$8,010,400							-		-$10,500,000	-$8,010,400
2021	$10,500,000	$7,486,355							-		-$10,500,000	-$7,486,355
2022	$48,000	$31,984	1,192,136	77,120	2,188	1,231,436	(25,735)	(10,976)	2,466,169	1,643,393	$2,418,169	$1,611,409
2023	$48,000	$29,892	2,483,427	158,513	4,486	1,231,436	(52,427)	(22,306)	3,803,128	2,368,588	$3,755,128	$2,338,696
2024	$48,000	$27,936	3,880,106	243,644	6,866	1,231,436	(80,099)	(33,999)	5,247,953	3,054,679	$5,199,953	$3,026,742
2025	$48,000	$26,109	5,388,758	335,673	9,341	1,231,436	(108,778)	(46,065)	6,810,366	3,704,864	$6,762,366	$3,678,755
2026	$48,000	$24,401	7,016,339	431,654	11,915	1,231,436	(138,488)	(58,511)	8,494,344	4,318,746	$8,446,344	$4,294,345
2027	$48,000	$22,804	8,770,192	527,410	14,589	1,231,436	(169,256)	(71,348)	10,303,023	4,895,741	$10,255,023	$4,872,936
2028	$48,000	$21,313	10,658,076	622,070	17,366	1,231,436	(201,110)	(84,584)	12,243,254	5,437,216	$12,195,254	$5,415,903
2029	$48,000	$19,918	12,688,176	728,273	20,163	1,231,436	(234,077)	(98,229)	14,335,743	5,950,100	$14,287,743	$5,930,181
2030	$48,000	$18,615	14,869,138	845,285	23,145	1,231,436	(268,185)	(112,293)	16,588,527	6,434,840	$16,540,527	$6,416,225
2031	$48,000	$17,397	17,210,086	968,104	26,351	1,231,436	(303,462)	(126,785)	19,005,729	6,890,369	$18,957,729	$6,872,971
2032	$48,000	$16,259	19,720,649	1,098,763	29,573	1,231,436	(339,939)	(141,717)	21,598,764	7,318,349	$21,550,764	$7,302,090
2033	$48,000	$15,196	22,410,986	1,213,692	32,915	1,231,436	(377,646)	(157,098)	24,354,285	7,712,340	$24,306,285	$7,697,145
2034	$48,000	$14,201	25,291,820	1,349,729	36,379	1,231,436	(416,613)	(172,938)	27,319,813	8,085,654	$27,271,813	$8,071,453
2035	$48,000	$13,272	28,374,461	1,483,983	39,969	1,231,436	(456,872)	(189,250)	30,483,727	8,432,034	$30,435,727	$8,418,761
2036	$48,000	$12,404	31,670,839	1,650,004	43,689	1,231,436	(498,454)	(206,043)	33,891,471	8,761,562	$33,843,471	$8,749,158
2037	$48,000	$11,593	35,193,540	1,789,292	47,542	1,231,436	(541,393)	(223,330)	37,497,087	9,059,743	$37,449,087	$9,048,150
2038	$48,000	$10,834	38,955,835	1,938,334	51,532	1,231,436	(585,723)	(241,121)	41,350,293	9,337,364	$41,302,293	$9,326,529
2039	$48,000	$10,125	42,971,720	2,113,775	55,888	1,231,436	(631,476)	(259,428)	45,481,914	9,598,755	$45,433,914	$9,588,629
2040	$48,000	$9,463	47,255,954	2,282,116	60,179	1,231,436	(678,690)	(278,264)	49,872,731	9,837,100	$49,824,731	$9,827,637
2041	$48,000	$8,844	51,824,095	2,450,550	64,619	1,231,436	(727,398)	(297,641)	54,545,660	10,055,233	$54,497,660	$10,046,389
Total	$23,960,000	$14,169,581	427,826,333	22,307,983	598,695	24,628,717	(6,835,821)	(2,831,927)	465,693,980	132,896,669	$443,733,980	$117,037,352